TIME-REVERSING ARRAY FOCUSING IN SHALLOW WATERS

David R. Dowling, Assistant Professor
Department of Mechanical Engineering and Applied Mechanics
University of Michigan
Ann Arbor, Michigan 48109-2121
Phone: (313)936-0423, FAX: (313)764-4256
E-mail: drd@engin.umich.edu

Award Numbers: N00014-96-1-0040, N00014-97-1-0628
Shallow Water Acoustics

LONG-TERM GOALS

The long term goals of this project are: i) to predict and understand time reversing array (TRA) retrofocus size and longevity in a shallow water acoustic environments based on acoustic, geometrical, and environmental parameters, and ii) to deduce the effectiveness of using a TRA for monitoring and/or determining the acoustic properties of unknown environments.

SCIENTIFIC OBJECTIVES

This project seeks to determine TRA retrofocus size and longevity in the presence of: i) dynamic random shallow-water internal-wave volume refraction, ii) dynamic random surface scattering, iii) deterministic soliton internal-wave volume refraction, and iv) typical shallow-water wave guides. In particular, the influence of acoustic frequency, array size, source array range, and dynamic mulitpath sound-channel structure on time-reversing array retrofocusing is not completely understood. The challenge is to separate the various influences and impacts of propagation complexities (bottom losses, water-column dynamics, surface scattering, etc.) so that the phenomena primarily responsible for TRA retrofocusing limitations can be identified.

APPROACH

This project exploits the established narrowband formulation of a time-reversing array. Simple analytical propagation and scattering models involving one or two acoustic paths between the source and array are used to develop insight into how propagation parameters interact to determine the size and longevity of the time-reversing array's retrofocus. Parabolic equation (PE) computations (using RAM; Collins 1993, 1994) are being developed to address more complex situations. The single-path analytical work involves acoustic propagation in a dynamic random media generated by a superposition of linear internal waves, and acoustic scattering from a dynamic random rough ocean surface. Results are obtained via formally averaged second moments from the PE and Kirchhoff approximations. The two-path analytical work involves direct and thermocline-reflected propagation paths as well as scattering from a deterministic soliton traveling on the thermocline. Here, to render the formulation manageable, acoustic scattering from the soliton is treated with the Born approximation. Given the simplicity of the analytical work relative to the real ocean, PE computations for more realistic sound propagation in a shallow water sound channel are also underway. The first step here involves matching

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 1997**	2. REPORT TYPE	3. DATES COVERED **00-00-1997 to 00-00-1997**
4. TITLE AND SUBTITLE **Time-reversing Array Focusing in Shallow Waters**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Michigan,Department of Mechanical Engineering and Applied Mechanics,Ann Arbor,MI,48109**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**3**	

computed PE retrofocusing results to analytical modal sum results in simple range-independent environments. Extension of the PE computations to realistic shallow water environments is the next step.

WORK COMPLETED

The analytical work involving dynamic random volume refraction, dynamic random rough surface scattering, and the deterministic environment containing a soliton propagating on a thermocline has been completed. The later study includes retrofocusing results for a static two acoustic path environment. The predicted retrofocusing results include parameter studies of acoustic source-array range, acoustic frequency, overall round-trip time delay, and environmental parameters.

The initial RAM parameter studies are now underway. To date, comparisons have been made between PE-computed focal size and focal amplitude and similar results from an analytic modal sum propagation model. Initial results look good although various refinements are necessary.

RESULTS

A variety of idealized shallow water propagation complexities were analyzed for their impact on time reversing array retrofocusing. It was found that a dynamic random media composed of a superposition of linear internal waves convecting a gradient in the sound-speed profile would not significantly impact the performance of a time reversing array for overall round trip time delays of less than a few minutes at an acoustic frequency of 1 kHz. On the contrary, TRA's were found unable to exploit time-dependent acoustic scattering from a dynamic rough ocean surface. However, a TRA will always exploit a time-independent specular reflection from the ocean surface. The retrofocusing studies of a deterministic medium incorporating a thermocline yielded interesting findings both with and without the inclusion of volume scattering from a soliton internal wave. When the wave is absent and the array is deployed below the thermocline, the array was found to focus incorrectly when it was not large enough to differentiate the directions of the two propagation paths, and when the thermocline-bounce path involved transmission of significant acoustic energy through the thermocline which could not be detected by the TRA. When a moving soliton is present, the TRA retrofocus size and amplitude were found to depend on the soliton location and size. However, as with the random internal waves, the soliton moves slowly enough so that successful TRA operations should be possible at ranges of order 1 km at acoustic frequencies of 1 kHz. Details are presented in Khosla and Dowling (1997).

IMPACT/APPLICATIONS

The analysis of TRAs shows that they should be effective in shallow ocean waters unless the dominant propagation path includes time-dependent surface scattering because both deterministic and random internal waves do not move quickly enough to prevent TRA operations. This finding suggests that it should be possible to use TRAs for underwater communication and ocean monitoring over ranges of several km or more. Eventually, the combination of dynamic random media and PE-computed multipath propagation

simulations should enhance the reliability of these predictions. Interestingly, the two-path analysis completed as part of this project shows that occasional mismatches in the source-array-thermocline geometry causes spurious retrofocusing just like the findings of the oceanic experiment conducted by the international team headed by Drs. Kuperman and Hodgkiss of Scripps Institute of Oceanography.

TRANSITIONS

The results of this project should aid in the design of further experiments, and eventually, TRA sonar hardware.

RELATED PROJECTS

This project runs parallel to the on-going 6.2 nonlinear acoustic retrofocusing studies under the direction of Dr. Ronald Roy at Boston University and Dr. Steve Kargl at APL-UW. In addition this research project, will soon draw on the 6.2 experimental retrofocusing results obtained in the Mediterranean Sea by an international research team headed by Drs. William Kuperman and William Hodgkiss of SIO. This project uses the PE code developed by M. Collins at NRL.

REFERENCES

Collins, M.D. [1993] "A split-step Padé solution for the parabolic equation method," *JASA*, Vol. 93, 1736-1742.

Collins, M.D. [1994] "Generalization of the split-step Padé solution," *JASA*, 96, 382-385.

Khosla, S.R. and Dowling, D.R. [1997] "Time reversing array retrofocusing in simple dynamic underwater environments," submitted to *JASA*, Nov. 1997.